University of Alberta

General Purpose Simulation for Mine Modeling

by

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Abstract

The mining industry, similar to other industries, is continuously striving to increase productivity and reduce unit costs of production. With the complexity and inter-connectivity of the systems involved in a large mining operation, it is often impractical to experiment with the systems themselves. Simulation can be an effective tool in evaluating the effect of changes. The type of simulations carried out will vary depending on the purpose and how the final outcome will be utilized. A simulation may involve a sub-system of the operation or the entire operation. In this thesis two simulation models are considered of varying scales. The first simulation is of a mine hoisting system and the effect that a simple dispatching algorithm can have on the production of the hoist. The second simulation involves the overall simulation of a large scale surface mining operation. The surface mine simulation is verified against published data and then the effects of changes to the base model are investigated.

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List of Symbols, Abbreviations and Nomenclature

SLAM Symbols	Definition
ACTIVITY	If it from a QUEUE it is a service activity and represents the time required for a server to complete its task If it is from any other node it represents the delay required for an entity to move from one node to the next
ALLOC	Subroutine used to control the function of the AWAIT node
ALTER	Changes the capacity of a resource
ASSIGN	Assigns values to SLAM variables
AWAIT	Resource mode: Delays an entity until the required resource is available Gate mode: Delays an entity until the gate is open
CREATE	Generates entities within the network
Entity	Object which is used to represent something moving through the system e.g. a load or a truck
FINDAR	Subroutine to locate entries in an array
LL(x)	Local alphabetic variable
OPEN / CLOSE	Nodes to change the status of a gate
PREEMPT	Entities at a pre-empt node have priority over entities at AWAIT nodes
QUEUE	Delays entities until a server is available
RESOURCE	Resources are finite assets used in a simulation
Server	Asset which performs an activity after a queue e.g. a shovel
XX(x)	Global real variable

Chapter One: Introduction

The object of this thesis is to provide an insight into the design and use of different scales and types of modeling in the mining industry utilizing a single general purpose simulation language. The simulation language utilized in this study is AWESIM©, which is the Windows© operating system implementation of the original SLAM II© language. Mining operations, whether an underground or surface operation, are complex and intricate systems. It is very difficult to accurately predict what the outcomes of physical or operational changes will be on the system. It may be a simple matter to look at a single aspect in isolation, and predict how it will affect the operation, but how it will affect the overall operation may not be as obvious. [Hoare, R.T. and Willis, R.J. 1992; Sturgul, J.R. 2001; McIntosh, S.L. 1999]

1.1 Background

It is important to first lay some ground work out with respect to the various types of simulations that are possible, the languages and systems that are available and how they have been implemented with respect to the mining industry.

1.2 Types of Simulation

It is possible to categorize simulations by several different methods. They may be categorized as discrete or continuous, deterministic or probabilistic and dynamic or static. In discrete event simulations, the events are taken to occur at specific instances of time while in a continuous simulation, the events are taken to occur continuously with respect to time. Continuous simulation techniques are required when variables are changing in an analog fashion over time. These variables can be represented by differential equations

which calculate the changes in a variable with respect to time, (e.g. material moving along a conveyor belt) [Law and Kelton, 1991].

In a deterministic model, once an initial set of conditions are determined, the outcome can be calculated by solving a series of equations and the results will always be the same for those inputs. Through the use of probabilistic inputs, that is inputs based on probability distributions, random values within a specified range are generated. The use of probabilistic models provides for a distribution of outcomes to be investigated. This type of modelling can provide the modeller not only with the expected or average value, but also with a range of outcomes.

Finally in a static simulation, the initial variables are assigned values and the equations solved which provides a 'snap-shot' of the system at that instance in time. In a dynamic simulation, the system is allowed to run for a period of time and the state of the system is monitored over that time. The time period that the system is allowed to run for can be a set period of time such as one shift, one week or one year. The period may also be determined by choosing different targets. These may be production targets such as five million tonnes of coal being produced, the total number of operating hours on a piece of equipment being reached or some other measure.

Simulations would be classified as a combination of these basic types. The simplest would be a discrete, deterministic, static model and the more complex being the continuous, probabilistic, dynamic model.

1.3 Simulation in Mining

Most early simulation work was carried out in the manufacturing industry to improve the design of the manufacturing operations [Law and McComas, 1992]. Manufacturing is one

of the largest industrial segments and has therefore received the most attention from the software manufacturers in developing simulation systems. Most of the specialized simulation packages and software that has been developed was tailored to this industry [Banks, 1996].

The number of simulation languages and packages increased rapidly during the 1990's. Two trends emerged during this rapid growth. Packages were developed to minimize the amount of programming knowledge required by the person carrying out the simulations, instead providing a series of pre-defined blocks that could be connected together to create the simulation. The second trend was the development of animations to go along with the simulations. The animations were ether integral to the simulation or carried out post simulation [Law and McComas, 1992].

While early simulations and modeling were implemented using general purpose programming languages such as FORTRAN, modern simulations are generally implemented utilizing either a simulation language environment or a simulator. A simulation language environment is a special computer language which includes tools and constructs useful in developing simulation models. A simulator is much more specific and requires little or no programming ability. A simulation model built using a simulator is generally built from menus, graphical elements and pre-built blocks.

Some of the common simulation language environments that have been used in the mining industry include GPSS (Wolverine Software Corporation, SIMAN/CINEMA (Systems Modeling Corporation) and AWESIM/SLAM II (Pritsker Corporation). The simulators that have been utilized in the mining industry include WITNESS (Lanner Group), AutoMod II (AutoSimulations), and ARENA (Systems Modeling Corporation).

1.4 Simulation Language Environments

One of the most commonly used simulation language environment is GPSS (General Purpose Simulation Software). GPSS has been used to model both underground and surface mining operations with a great deal of success [Sturgul and Smith 1993; Sturgul, J. 2000]. The popularity of GPSS is largely due to its low cost when compared to other simulation environments. GPSS is a discrete event modeling package.

It is possible to animate the GPSS simulations utilizing the PROOF animation software. Animation software may be either post simulation or concurrent. PROOF is a post simulation animator which utilizes a script file that is generated by the GPSS simulation. The script file is contains the control statements for the animation [Sturgul, J. 2001].

The SIMAN language is another general purpose SIMulation ANalysis program which can be used to model complex systems [Banks, J 1996]. The animator which can be used with SIMAN is called CINEMA (Systems Modeling 1985). CINEMA is not a separate program but rather a module which is added onto the SIMAN software and is used to design and run animations of the SIMAN models. The animations run concurrently with the simulation.

Most of the work done with SIMAN/CINEMA has been in the manufacturing area, although it has been used in other industries such as banking, electronics, food service, health care, and transportation. [Profozich, D. M.; Sturrock, D.T.; 1995]

SIMAN/CINEMA has an object-oriented, graphical user interface. The interface allows users to build models through the use of icons and dialog boxes. Model building is quite rapid by simply selecting icons, locating them on the screen, and filling in forms. SIMAN

modeling constructs are actual verbs, which describe specific functions (e.g., ASSIGN, COUNT, or DELAY). SIMAN also allows for user-named attributes, variables, and other language constructs allowing modellers to create readable, self-documenting descriptions of their systems. SIMAN, unlike GPSS, can carry out both discrete and continuous simulations [Pegden, C.D., Shannon, R.E. and Sadowski, R.P. 1995].

The animation development is performed concurrently with model definition. In animating a particular type of object (e.g., queue), the modeller selects from a list of all of the objects of that type that have currently been defined (e.g., OperatorQue, MachineBuffer, InspectorWait). The user may interrupt a simulation run, modify the animation, and continue the run immediately without exiting the program.

AweSim is a general-purpose simulation system. AweSim is similar to SIMAN in that it can deal with both discrete and continuous simulations. [Banks, J. 1996]

The similarity of SIMAN and SLAM resulted in a court case between Dennis Pegden, the original developer of SLAM and author of the SIMAN language and Alan Pritsker, the person who enhanced and popularized SLAM. Portions of the original version of SLAM were based on GASP and Q-GERT, two languages that were proprietary to Pritsker and Associates [Nance, Richard E. 1993].

The animation is similar to GPSS in that the simulation is carried out by executing a script in the animator. AweSim includes the Visual SLAM simulation language to build networks, sub-networks, discrete event, and continuous models. Network models require no programming yet allow user-coded inserts in Visual Basic or C. Discrete event and continuous models can be created using the object-oriented technology of Visual Basic, C or Visual C++ and can be combined with network models.

The AweSim animator allows one to develop and display multiple animations for a single scenario. For example, the modeller can create one animation of a system at an aggregate level and another at a department level, side by side in separate windows. The two views may then be displayed by associating the animations with the current scenario and running the simulation. Animation constructs, called actions, correspond to elements in an AweSim network model. For example, the ACTIVITY action shows movements of a symbol. It requires that the modeller define a symbol, a graphical path location where movement of the symbol will be shown, and the number of an activity in the AweSim model to which to tie the movement. Other actions are provided to display resource status, items in a queue, variable values, and other system status conditions. The symbols manipulated by the animator are of two types: graphical items one wants to display or move, and the background on which they will appear. These symbols are stored in standard Windows bitmap format, allowing them to be exchanged between programs using the Windows clipboard [O'Reilly, J. and Pritkser, A. 1997. O'Reilly, J. 2002]. The AweSim Interactive Execution Environment (IEE) provides an interface with an executing simulation. The modeler may examine, modify, save, or load the current system status using the IEE. The IEE supports the debugging of a model under construction and verification of a completed model. The analyst may use the IEE to develop and analyze alternative control strategies for a system or to demonstrate the operation of the model to non-modellers. The IEE control panel lets you advance through the model step-by-step or by setting breakpoints. At any point you may examine variable values, statistics, or queue entries or save the system status in order to reload and

experiment with alternative scenarios. [O'Reilly, J. and Pritkser, A. 1997. O'Reilly, J. 2002]

1.5 Simulators

Simulators provide a means of quickly creating models with extensive animation properties and generally require little user programming. Simulator software which has been utilized by the mining industry includes WITNESS©, AutoMOD© II, and ARENA©.

1.6 WITNESS©

WITNESS©, is primarily a business simulation system. It provides enough flexibility to model the working environment, simulate the implications of different business decisions and understand many processes.

WITNESS© was designed with simplicity in mind. It is based on a building block design making use of modular and hierarchical structures. It is a Windows© implementation making it extremely interactive. It contains a large range of logic and control options and includes elements specific for many industries including manufacturing, process industries, health and finance sectors. It has the ability to link directly with many industry standard databases including ORACLE©, SQL Server, and ACCESS©. WITNESS is also capable of being directly linked to spreadsheets for both input and output. In keeping up with today's requirements, it can also save in XML formats and generate HTML reports. Optional modules are available which provide virtual reality, optimization, and linkage to VISIO© and CAD [http://www.lanner.com/en/home/, 2007].

1.7 AutoMod© II

AutoMod© II is an industrial simulation environment which utilizing CAD-like drawing tools for model design and layout. The control logic and material flow is controlled using

an engineering oriented language. Modeling is carried out utilizing three dimensional details. AutoMod© II is most suited to manufacturing, material handling and distribution systems. The CAD capability ensures that the physical layout is accurate.

Included within AutoMod© II is a set of 'expert based' movement systems developed by AutoSimulations Inc. based on their expertise and experience in industrial automation. The model logic is automatically generated for the user by the geometry of the model. Animation is an automatic part of the simulation [Norman, V. 1990].

AutoMod© II is essentially two different programs. The design portion is where the physical and logical model is defined. Once the model is created, it is then compiled into an executable model and the simulation and animation run concurrently. The executable model is fully interactive and may be stopped at any time to examine statistics and model status.

1.8 ARENA©

ARENA© is the simulation system from Systems Modeling Corporation that allows models to be created for many different systems. The software utilizes an object-oriented approach so that model design is done in a totally graphical environment. Systems are specified by placing modules in a layout to define the model. These modules represent components such as machines, operators and material handling devices. ARENA© was released in 1993 and was built on the SIMAN© simulation language. Once the model has been created graphically, ARENA© will generate a SIMAN© model used to perform simulation. There are several built in graphical modules which can be used to build the model. It is possible to custom design modules to tailor the modules to meet the needs of the simulation. The collection of user-created modules is contained inside an Application

Solution Template (AST) and can be re-used in other simulation models. The animations generated by ARENA© may be run concurrently with the simulation model or in a post-process mode [Hammann, J., Markovitch, N. 1995].

Chapter Two: Modeling & Simulation

As was stated earlier, modeling and simulation are means of creating representations of physical systems so that experimentation may take place without either building or affecting a currently operating system. By utilizing a simulation it is often safer, cheaper and quicker to observe the new system or to see the effects of any changes and how it may react in the real world. When a simulation or model is created, it is not necessary to reproduce the exact details of all the components of the system, but instead to accurately depict the aspects of the system under investigation. Consider the simple example of a truck-shovel simulation. If the purpose of the simulation is to determine the optimum number of trucks, it is not necessary to model the physical truck itself. The important components of the truck model would be the capacity of the truck, travel times loaded and empty, loading and dumping times and its availability. In this system the truck does not need to be modeled as to its individual components, the type of break downs that it may suffer or the time to repair the truck. A second, separate scenario involving the trucks could be looked at to determine how the number of repair shops and types of breakdowns would affect the truck productivity. In the second scenario it would be important to model the failure rates of various truck components or systems and the repair times for these components.

These breakdowns and repairs could best be modeled using a statistical approach based on probabilistic models. If an occurrence were to be known with absolute certainty, then a single value could be assumed and a deterministic solution found.

2.1 Probability Distributions

Central to any probabilistic simulations are the probability distributions which are used to generate variables. Random variables are assigned values based on chance. The distributions may be continuous or discrete. For example the rolling of a die would be a discrete event since there are exactly six possible outcomes from rolling the die. A continuous distribution would be one in which there is an infinite number of possible outcomes.

In calculating values for use in simulations there are two important components. The first is that a random number be generated and that the number generated should be from a specific probability function which best suits the type of variable being modeled. In generating random numbers, the computer generates a pseudo-random number based on an initial seed value. The sequence of numbers generated is for all purposes a random string of numbers; however, as long as the same seed value is used the same sequence of numbers will be generated. This is important in conducting modeling experiments so that changes in the outcome are due to the changes in the conditions and not due to variations in the sequence of numbers used in the simulation. The common distributions that are used to model physical processes in mining simulations are: uniform, triangular, normal, exponential and Poisson.

2.1.1 Uniform Distribution

In a uniformly distributed variable there is an equal chance for all events to occur. The uniform distribution has also been called the rectangular distribution. This distribution would describe the rolling of the die in a game of chance. In an unbiased die, there is an equal opportunity for each of the six sides to appear on top. It is also used when little is

known about the random variable except for the expected minimum and maximum values.

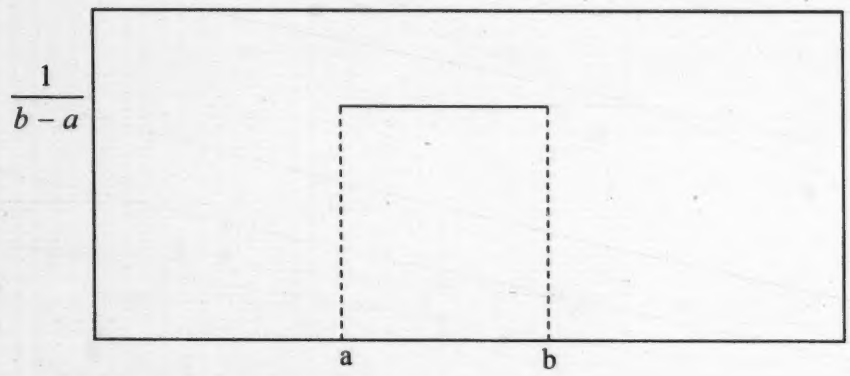

Figure 2-1: Uniform Distribution

In Figure 1, the probability function is given by:

$$f(x) = \frac{1}{(\text{Upper Bound- Lower Bound})}$$ Equation 1 [Pritsker, A. 1995]

2.1.2 Triangular Distribution

The triangular distribution is used when there is only limited information available about the distribution of values. If the minimum and maximum values are known, then a uniform distribution would usually be assumed. If the most likely value were also known, then a triangular distribution would be suitable. The triangular distribution can be described mathematically as:

$$f(x) = \begin{cases} \dfrac{2(x-a)}{(b-a)(c-a)} \; for \; a \le x \le c \\ \dfrac{2(b-x)}{(b-a)(b-c)} \; for \; c \le x \le b \end{cases}$$ Equation 2 [Pritsker, A. 1995]

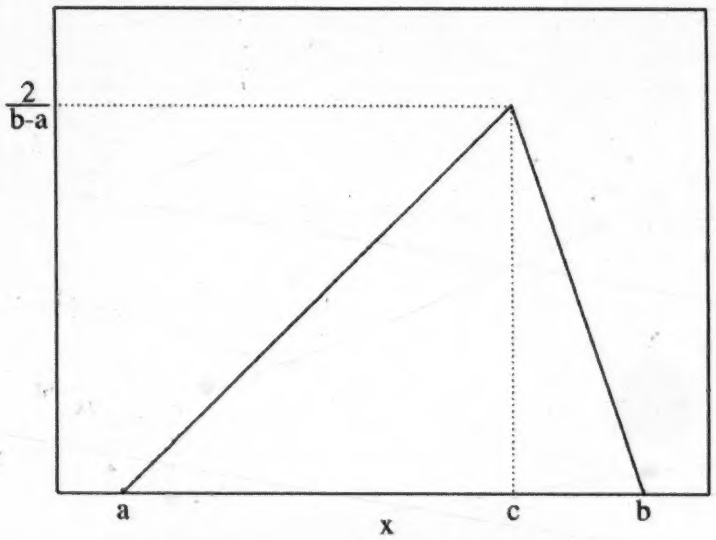

Figure 2-2: Triangular Distribution

2.1.3 Normal Distribution

The normal distribution is central to statistical theory and practice. Graphically the curve resembles a bell and is defined by two parameters: the mean value and the standard deviation. Figure 3 shows an example of the normal distribution. Normal distributions are also known as Gaussian distributions and describe the majority of physical processes that take place. In mining simulations it is often used to model such things as vehicle travel times since it is particularly good when vehicles are restricted to a top speed. [Sturgul 2000]. The normal distribution is described by equation 3:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\left[\frac{(x-u)^2}{2\sigma^2}\right]}$$ Equation 3 [Pritsker, A. 1995]

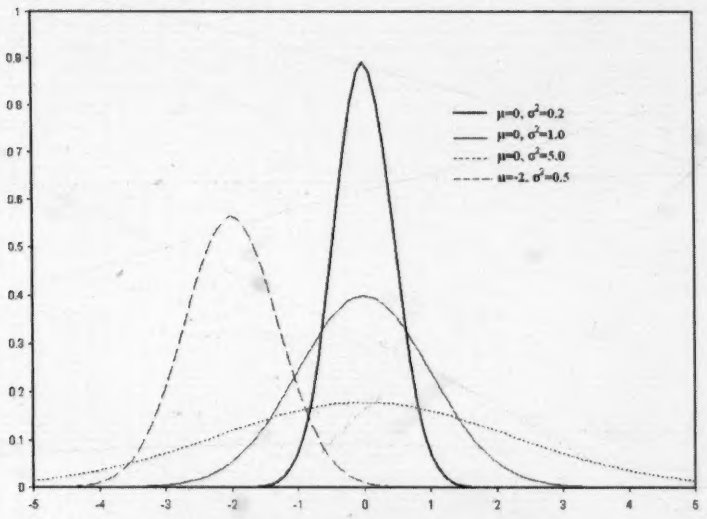

Figure 2-3: Normal Distribution

2.1.4 Poisson Distribution

The Poisson distribution is a discrete probability distribution for the frequency of a particular event in a given period of time. In queuing theory to describe the random number of arrivals, or service demand in a given time period. The Poisson distribution is described by the equation:

$$f(x) = \frac{e^{-\lambda}\lambda^{x}}{x!}$$ Equation 4 [Pritsker, A. 1995]

Where λ is the mean of the occurrences, x is the number of occurrences and e is the base of the natural logarithm. For instance, if the events occur on average every 4 minutes, and you are interested in the number of events occurring in a 10 minute interval, you could use a Poisson distribution to model this with λ = 10/4 = 2.5.

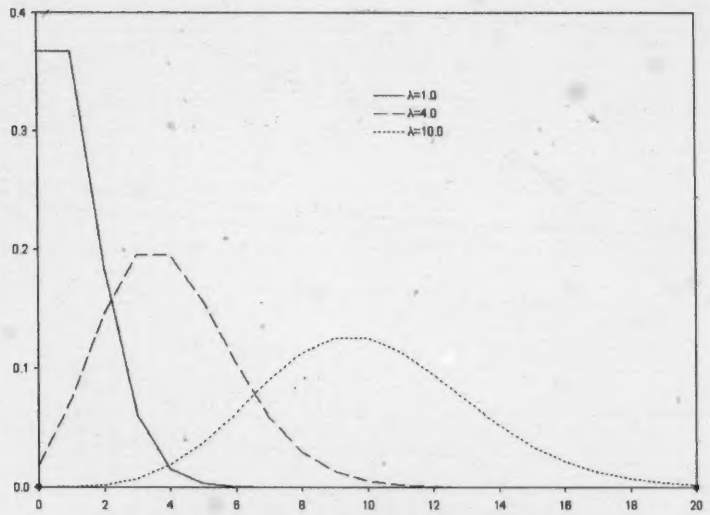

Figure 2-4: Poisson Distribution

2.1.5 Exponential Distributions

Exponential distributions are often used to model the time between independent events that happen at a constant average rate. It is a non-symmetric distribution based on a single parameter λ. In queuing theory, the inter-arrival times (i.e. the times between customers entering the system) are often modeled as exponentially distributed variables with the average arrival time equal to λ. The equation for the exponential distribution is given in equation 5.

$$f(x) = \lambda e^{-\lambda x}$$ Equation 5 [Pritsker, A. 1995]

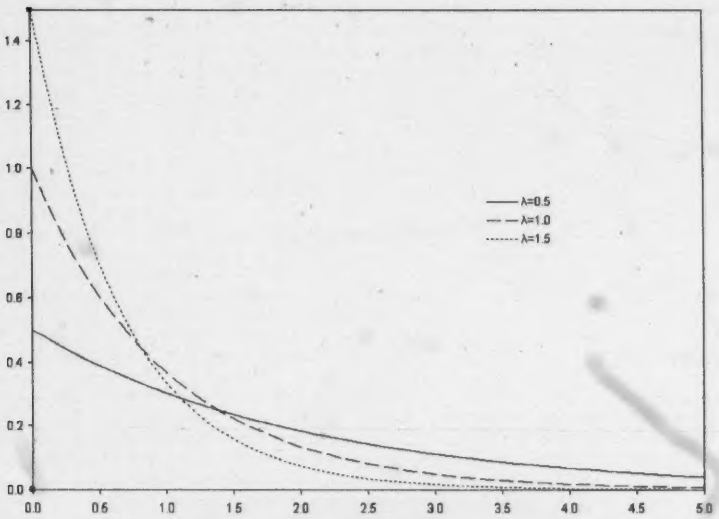

Figure 2-5: Exponential Distribution

Chapter Three: Underground Hoisting Model

3.1 Background

The first problem which was investigated involved the simulation of a single hoist in an underground mine. The problem was divided into three parts. First the existing operation of the hoist system was simulated, secondly a scheduling algorithm was incorporated into the model and finally an animation of the system was created.

Data was obtained on the current operation of the hoist system. No times were provided for loading and unloading of the skip or the average size of the loads being transported. The information provided included the frequencies of requests and the duration of the trips to the 20 working levels and surface. The raw skip data is presented in Table 1. The operation of the skip was complicated by a series of interruptions involving scheduled maintenance, blasting, crew changes and inspections. These interruptions are summarized in Table 2. No information was available for breakdowns; so unscheduled delays were not considered.

Level	Down		Up		Time
	Freq	Cum Freq	Freq	Cum Freq	
400	0.0017	0.0034	0.0017	0.0048	0.789
600	0.0135	0.0300	0.0106	0.0344	0.922
800	0.0070	0.0439	0.0065	0.0526	1.056
1000	0.0082	0.0601	0.0065	0.0708	1.119
1200	0.0000	0.0601	0.0006	0.0724	1.322
1400	0.0153	0.0903	0.0054	0.0876	1.456
1600	0.0106	0.1113	0.0059	0.1041	1.589
1800	0.0100	0.1310	0.0054	0.1192	1.615
2000	0.0029	0.1368	0.0012	0.1225	1.722
2200	0.0423	0.2204	0.0241	0.1899	1.856
2400	0.0117	0.2435	0.0047	0.2031	1.989
2600	0.0787	0.3990	0.0499	0.3427	2.122
2800	0.0352	0.4686	0.0235	0.4084	2.389
3000	0.0188	0.5057	0.0153	0.4512	2.656
3200	0.0047	0.5150	0.0024	0.4579	2.789
3400	0.1955	0.9014	0.1503	0.8783	2.922
3600	0.0041	0.9095	0.0100	0.9063	3.189
4000	0.0217	0.9524	0.0170	0.9538	3.242
4160	0.0235	0.9988	0.0159	0.9983	3.296
4330	0.0006	1.0000	0.0006	1.0000	3.409
TOTAL	0.5060		0.3575		

Table 3-1: Frequency and duration of requests for the skip

Activity	Time	Time in Minutes	Duration minutes
Daily			
Rope inspections	3:30	390	60
	23:00	1380	60
Mechanical run	14:00	840	14
Man shifts	6:30	390	120
	11:45	705	30
	14:30	870	120
	22:30	1350	60
Weekly			
Cage	4:30	270	120
Counter-weight	1:30	90	60
Electrical	13:00	780	60
Blasting			
Blasts occur every 2.3 days	11:00	660	60
Total Delays/ week in minutes			887
%Delays	8.80%		

Table 3-2: Hoist delay times and durations

The exponential distribution was used to create the requests for both the up and down requests for the skip. The exponential distribution was chosen since it has been shown Requests for trips from the surface to the working levels were created with a mean of fifteen minutes, and requests for trips from the working levels to surface utilized a mean of ten minutes.

3.2 Methodology

The following assumptions were made in carrying out this study:

- One request for the skip, involved only one load. This meant that it was not possible to combine two loads going down – the skip would have to deliver the first load and return to surface for the second load.

- Requests for trips from the surface to the working levels were created following an exponential distribution with a mean of fifteen minutes, and requests for trips from the working levels to surface followed an exponential distribution with a mean of ten minutes.
- All interruptions were given equal weighting, and would not interfere with a trip in progress.
- All interruptions were independent and could not be combined.
- All down trips originated at the surface; all up trips terminated at the surface.
- Load and unload times are unknown, so are not considered

3.3 Modeling Method

3.3.1 Phase I

The modeling package used was AweSim®, which is based on the Visual SLAM® language. This is a Microsoft Windows® based modeling package, which allows for the creation of network, discrete and continuous models. It also has the ability to incorporate user written routines and provides an interface for adding animation to the simulation. The hoisting simulation was created using basic network modeling.

The skip was modeled as a RESOURCE block, with a single unit available. RESOURCE blocks are used to represent limited resources in a model. The resources are used in modeling a process and released back to the system once the process is completed. Two possible methods of modeling the requests for the skip were considered. The first method, which is the simplest to setup, is the most complicated to view. Two CREATE nodes are used - one node to generate skip up requests and a second for the skip down requests. The request would then be routed to/from the appropriate level based on the

frequency of the requests in Table 1. This would require each of the CREATE nodes having twenty probabilistic branches emanating from them, all converging (total of forty) to a single AWAIT node to seize the skip. A simplified version illustrating this concept is shown in Figure 1. Only four levels are shown for each of the create nodes.

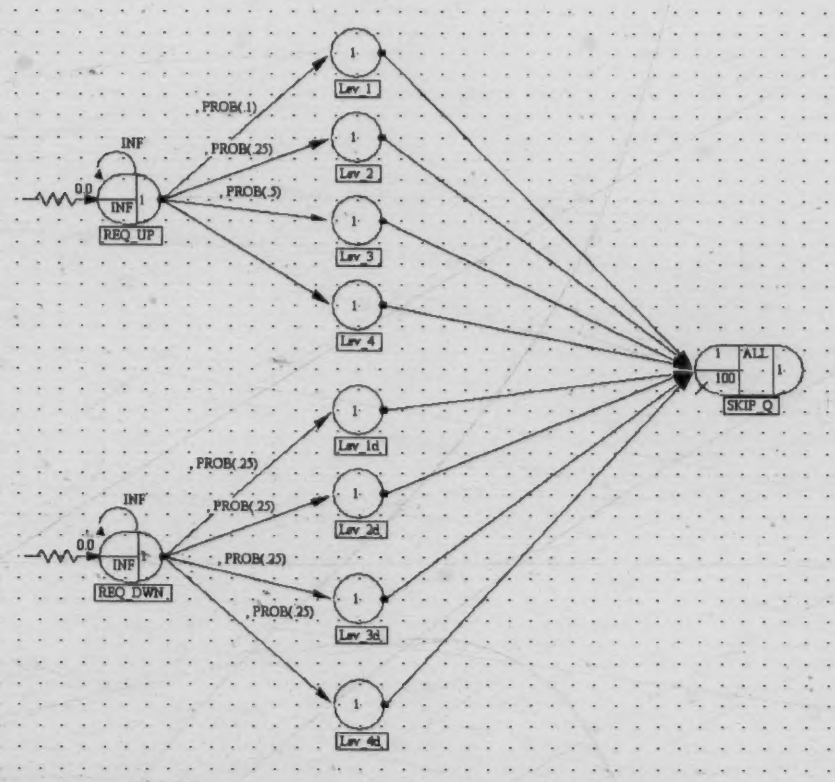

Figure 3-1: Simplified Load Creation Nodes Using Probability

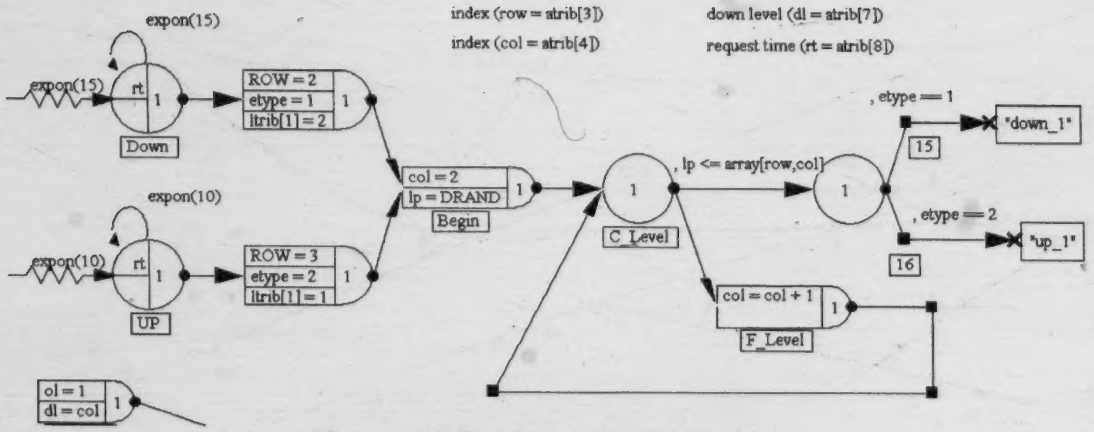

Figure 3-2: Load Creation Using Arrays

The second method, involves using the cumulative probability for each of the trip requests. Once the cumulative probability is known for a given request, a random number (between 0 and 1) may be generated, and based on this distribution, a trip destination assigned. This method involves creating an array of the requests. The array was setup with the first row containing the destinations; the second row is the up request cumulative probabilities, the third row the down request probabilities and the fourth row contained the trip times. Two CREATE nodes are still used to differentiate the up and down requests. The entities created are tagged so that they will carry the information with them. These tags (attributes) store the direction (an up or a down entity), and the random number used to determine the destination.

In modeling the interruptions the choice was somewhat limited, if the desired effect was to be achieved, however four methods were investigated.

In using resources as model elements, their operation may be disrupted by using PREEMPT nodes. The PREEMPT node takes priority over the resource and will immediately seize it. This works well for modeling machine breakdowns, but in the skip operation, it is desired that the current trip be completed before it is removed from service.

A technique to overcome this problem would be to place a QUEUE node immediately after the AWAIT node. In this scenario the resource is seized, and without delay, the entity moves to the QUEUE node. Again without any delay, it is routed to the trip ACTIVITY. The trip ACTIVITY, since it now comes from a QUEUE is considered a service activity, and the resource will only be preempted after the service activity is finished.

A third method which could be utilized for the interruptions is to have the interruption requests arrive at AWAIT nodes, and wait for the resource in a file with a higher priority than the trip requests. This method would insure that trips were not interrupted in the middle.

A fourth method is to use an ALTER node. The ALTER node allows the modeler to decrease the quantity of resources available. If it cannot immediately decrease the resource, it will do so as soon as the resource is freed. The problem with this method is that the resource level cannot be altered below 0. If a second request is attempted when the resource is at 0, the request is not taken as a second request, but instead combines

with the first. This can then have the effect of increasing the number of available resources when the second alter node is reached.

The method used in this simulation was to use a combination of PREEMPT nodes for the interruptions, and a user written allocation (ALLOC) routine in the AWAIT node. The user written ALLOC routine is similar to the default one provided by Visual SLAM®. The difference is that the resource is not seized until after the activity following the user written ALLOC routine is completed. The interruptions are stored in file 1 and the load requests in file 2. This gives the interrupts a higher priority to the resource and insures that they are carried out first before the loads.

The model was simulated for a period of one week to accommodate all the scheduled interruptions.

3.3.2 Phase II

The second phase of the project involved modifying the model to incorporate a scheduling algorithm. This was done by inserting an ASSIGN node and a FINDAR node immediately after the AWAIT node. The assign node is used to set a global variable LL(1) to the opposite type of entity to the current one. At the FINDAR node the following logic is used:

Look for the first entity in the AWAIT queue (file 2) for a load moving in the opposite direction to the current one.

Check to see that this load is on the original path of the current load, and if it is it can be moved by the same request.

If a suitable entity is found, it is removed from the queue and sent directly to the load count collect node.

With the limited data available for the model, it was assumed that the skip must be empty to start a trip. Again, as was mentioned previously, it is assumed that the skip has the capacity to service only one request at a time.

An example of how the scheduling at the FINDAR node is utilized is as follows:

Assume the skip has a trip from surface down to level 19.

After reaching level 19, it is found that the next request is a down for level 18.

Without the FINDAR node the skip would return to surface, and then move down to level 18.

With the FINDAR node, the queue of waiting trips would be searched, and if there were an up request between level 19 and the surface, this trip would be serviced on the return trip to the surface.

A complete listing of the input and control statements may be found in Appendix A.

3.4 Results

In comparing the results from the two scenarios, it can be seen that the total number of loads (total requests) is unchanged: 1765 requests were generated in both cases. The number of loads moved through the system increased by 9%, from 1617 to 1764. This is a result of the 308 loads being carried when the skip was moving to service another request. The utilization of the skip decreased by 3% introducing some potential extra capacity. The original simulation had the skip utilized 99.6% and the scheduled simulation 96.2% of the time. Of this utilized time, 9% is accounted for in the interruptions.

Label	Mean Value	Standard Deviation	Number of Observations	Minimum Value	Maximum Value
No Scheduling					
move time	3.971	1.468	1617	0.789	6.592
time in system	725.844	241.493	1617	1.989	1088.831
With Scheduling					
move time	4.213	1.501	1456	0.922	6.592
time in system	104.922	107.825	1764	0.080	510.564

Table 3-3: Comparisons of length of time loads are in the system

The average queue length for loads was 122 with an average wait time of 11.5 hours. Under the scheduled scenario the load queue and wait times dropped to 18 loads and 1.6 hours – this is the most significant effect of the scheduling – it delivers the loads to where they are needed with a shorter delay. These results also show up in the time that loads are within the system. Table 3 is a summary of the time loads are in the system. The 'move time' in Table 3 is the time that a load is actually engaged in the hoisting operation, and the 'time in system' is the time from when a load (entity) is created, until it arrives at its destination (released). Since no change was made in the way the hoist operates, the 'move time' should be comparable in both scenarios.

A complete listing of the output for both the scenarios without scheduling and with scheduling is presented in Appendix A.

3.5 Animation

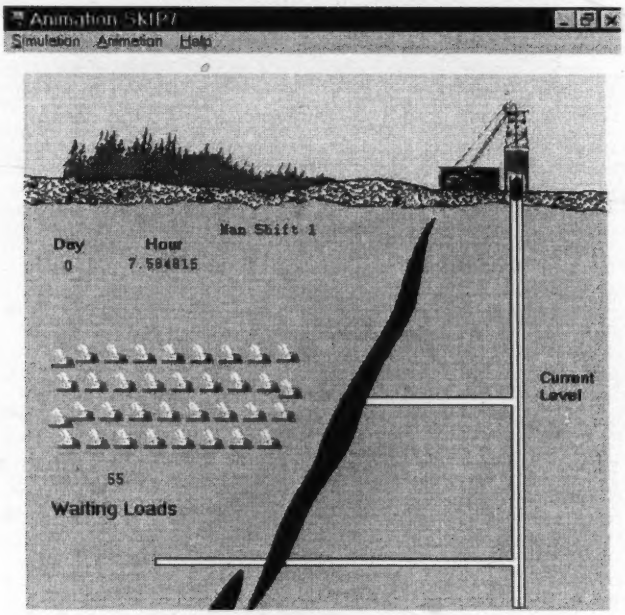

Figure 3-3: Sample Animation Screen

A final phase to the simulation was to introduce a simple animation. The animation serves as a visual aid in analyzing the operation of the model. In this case it proved valuable in detecting an error in the model logic. Originally the PREEMPT interruptions were being stored in the same file as the load requests. With the loads and interruptions in the same file, they were serviced in a sequential fashion. Any loads, which accumulated in the file, prior to the second interrupt, were serviced before the interrupt. By watching the interruptions as they occurred in simulated time, this was detected and the two files implemented.

Through the use of the animation it was also discovered that there were times when the skip was not utilized – no interruptions, and no loads waiting. The skip had sufficient

time to be able to clear the queue of waiting loads when it was running without interruptions.

3.6 Conclusions

In this simulation, it was possible through very simple scheduling, to increase the number of loads carried, but more importantly deliver the loads with increased efficiency. The scheduling showed a drop in utilization of the skip, indicating that the system has excess capacity. By re-scheduling some of the inspections, it should also be possible to decrease the queue length and have loads arrive to where they are needed sooner.

Animations can play an important role in the validation of models – they can provide insights into the operation of the model, which are not apparent when the numbers alone are considered. Through the use of the animation, it was not only possible to detect problems with the model, but it was easy to see when and why bottlenecks occurred.

Chapter Four: Surface Coal Mine Simulation – Base Model

4.1 Introduction

There has been a large amount of work carried out dealing with underground mines and the associated operations including the simulation of underground haulage [Corkal, N. et. al. 1997], underground materials handling systems [Lebedev, A. and Staples P. 1998] and underground mining techniques [Schafrik, S.J. 2001] [Sturgul, J. and Smith M. 1993]. Surface mines can be complex operations with numerous unit operations interconnected to deliver a final product. In assessing the equipment requirements to meet production targets it is essential that all the components be looked at together, and their interactions taken into account. Computer modeling and simulation allow the engineer to observe the effect that changes will have before they take place. When these effects are anticipated, effective planning and scheduling is possible.

Computer simulations allow the mine planner and scheduler to anticipate any problems, which may be encountered, and to be able to take precautions to mitigate the effect they will have on over-all productivity. Simulations have been carried out by others on mining trucks [Frimpong S., Changirwa R., Szymanski, J. 2003], truck-shovel interaction [Szymanski, JK, Srajer, V. and Kempke], [Pritsker, AB] and truck-shovel-plant interactions [Ellis, D. 2997][Sturgul, J. 1992]. There are few examples in the literature of complete surface mining systems having been developed. One model was developed using an object oriented approach and developing objects using C++ as the development language [Frimpong, S., Guo-Kang E. and Szymanski, J. 2004].

In constructing the simulation of the surface coal mining operation, it was desired to model the main sub-systems which contributed to the production systems. The first step

involved building a base model comprised of each of the sub-systems. It involved modeling the waste and coal hauls as well as taking into account the needs of the plant and the rail haulage system. No attempt to simulate the maintenance aspects of the operation (breakdowns/repairs) is included. This model will form a useful starting point for the development of more sophisticated simulations and animations.

4.2 Background

The mine, which will be simulated in this study, is loosely based on the Fording River operations of Fording Coal Ltd., located in south-eastern British Columbia. Although numbers were available on various aspects of the operation, the numbers did not always agree as to quantities of material moved. For this study the quantity of materials was taken to be 207,074 bcm of waste and 29,500 bcm of ore per day [2000 Mining Sourcebook]. The coal is cleaned in a wash plant producing 25,000 tonnes of clean coal per day. The coal is hauled from the plant to a terminal on the west coast for export. From the Crowsnest Coal website [http://www.crowsnest.bc.ca/revival2.html, 2007]:

"The distance from Sparwood to Roberts Bank is 2258 km (1,403 miles) and trains made the round trip in about 82 hours. At first only three trains were used but soon six were in operation and since then, many more have been added and the trains have increased in length to over 110 cars representing trains of over 14,900 tonnes."

The major equipment utilized in the simulation is based on the Fording River operation [2000 Mining Sourcebook] and is outlined below:

Waste

3 identical shovels with 44 m^3 bucket capacities

1 shovel with a 26 m^3 bucket

1 shovel with a 23 m^3 bucket

1 shovel with an 11.5 m^3 bucket

15 Caterpillar 793C trucks (220 tonne, 129 m^3 capacity)

16 Haulpak 830E trucks (218 tonne, 129 m^3 capacity)

1 Haulpak 930E truck (290 tonne, 184 m^3 capacity

Coal

2 Front-end loaders with 30 m^3 buckets

3 Front-end loaders with 15 m^3 buckets

14 Cat 789C 154 tonne trucks (special coal boxes)

Unit train

Cars hold 105 tonnes of coal.

Train is made up of 110 cars.

Round trip for a train is 82 hours including loading and unloading.

4.3 Preliminary Calculations

4.3.1 Scheduled hours

The operation runs 24 hours a day with 2, 12-hour shifts. The assumption will be that the haulage operations will loose 15 minutes at the start and end of each shift for shift changes (total of 0.5 hours), 2-15 minute coffee breaks (0.5 hours total) and one 30-minute lunch break (0.5 hour). All the equipment will break at the same time. This will

result in 10.5 hours of scheduled work per 12-hour shift. The entire operation will shut down for a 2-week maintenance break once per year (14 days). Total available hours will then be:

OH = (365 – 14) x 2 x 10.5 = 7,371 hours

4.3.2 Material Quantities

Annual Required

8.3 million tonnes of clean coal [http://www.mining-technology.com/projects/fording/, 2006]

The plant recovery is reported to be 66%, which would require 12.57 million tonnes of raw coal [2000 Mining Sourcebook].

Waste = 207,074 bcm/day [2000 Mining Sourcebook]

The waste density was taken as a combination of sandstone and shale since no actual density was available. (Sandstone 2.52 tonnes/bcm; shale 1.66 tonnes/bcm) [Cat Handbook]

Waste density = 2.1 tonnes/ bcm

Waste (weight) = 434,860 tonnes/day (152,610,000 tonnes per year)

Based on the above hours, this results in a production rate of 20,707.4 tonnes/hour

Coal = 29,500 bcm/day [2000 Mining Sourcebook]

Coal density = 1.16 tonnes/bcm (estimated based on the raw coal to clean coal ratio and the daily production reported)

Coal (weight) = 34,220 tonnes/day (12,011,220 tonnes per year)

Based on the 7,371 hours this results in a production rate of 1,629.5 tonnes/hour

4.4 Cycle Times

4.4.1 Waste Loading

Both truck types are similar in size and will be treated the same when loading from the shovels. The shovels of similar size will also be treated similarly. Assuming a 90% bucket fill factor (blasted rock average conditions) for all shovels.

Truck capacity = 129 m^3

44 m^3 Shovels

Buckets / truck = 129 / (44 x 0.9) = 3.25

With 3 buckets per truckload, the trucks would be hauling about 119 m^3 of waste or 185 tonnes.

26 m^3 Shovel

Buckets/truck = 129 / (26 x 0.9) = 5.5

With 5 buckets per truckload, the trucks will be hauling about 117 m^3 of waste or 182 tonnes.

23 m^3 Shovel

Buckets/truck = 129 / (23 x 0.9) = 6.23

With 6 buckets per truckload, the trucks will be hauling about 124 m3 of waste or 193 tonnes.

11.5 m^3 Shovel

Buckets/truck = 129 / (11.5 x 0.9) = 12.5

With 12 buckets per truckload, the trucks will be hauling about 124 m^3 of waste or 193 tonnes.

4.4.2 Coal Loading

The coal trucks are loaded with front-end loaders (FEL) and have special coal boxes. The trucks utilized are Cat 789C, which have a payload of 186 tonnes [Cat Handbook, 30ed]. The trucks could haul 186 tonnes per trip however; the standard box on this truck will only hold 105 m^3. The trucks are hauling 154 tonnes [2000 Mining Sourcebook] therefore it is assumed that over-sized coal boxes are used. Coal trucks could not be used to haul waste without serious overload problems occurring.

30 m^3 FEL

Buckets/truck = 154 / (30 x 0.9 x .95 tonnes/lcm) = 6.0

With 6 buckets per truckload, the trucks will haul about 154 tonnes per trip.

15 m^3 FEL

Buckets/truck = 154 / (15 x 0.9 x .95 tonnes/lcm) = 12.0

With 12 buckets per truckload, the trucks will haul about 154 tonnes per trip.

4.4.3 Estimated Loading Times

Waste

Average cycle times [Cat Handbook, 30ed] for truck loading

Exchange and maneuver = 0.6 minutes

Cycle times of 0.6 minutes/dipper

44 m^3 Shovels = 3 x 0.6 + 0.6 = 2.4 minutes/truck

26 m^3 Shovel = 5 x 0.6 + 0.6 = 3.6 minutes/truck

23 m^3 Shovel = 6 x 0.6 + 0.6 = 4.2 minutes/truck

11.5 m^3 Shovel = 12 x 0.6 + 0.6 = 7.8 minutes/truck

Coal

Average cycle times [Cat Handbook, 30ed] for truck loading will be taken at the high end. This results in a value of 0.7 minutes for the large FEL, and 0.6 minutes for the small one.

30 m^3 FEL = 0.7 x 6 = 4.2 minutes/ truck

15 m^3 FEL = 0.6 x 12 = 7.2 minutes/ truck

4.4.4 Travel Times

The average haul distances are currently about 2 kilometers, with the expectation that they will increase to 6 kilometers as mining progresses [http://www.canadianminingjournal.com/issues/oct99/page11_fording_river_coal.asp; 2001]

From the Cat productivity charts for the 793C [Cat Handbook, 30ed], travel times are taken for an average total rolling resistance of 10% (grades at Fording River are up to 8% [2000 Mining Sourcebook]. Dump and manoeuvre times are taken to be 1.0 minute.

Waste: Loaded, 6.0 minutes

Empty, 3.5 minutes

Coal: Loaded, 8.5 minutes

Empty, 11.0 minutes

For the coal haul the assumption was made that the plant is located in the valley, and therefore will result in a downhill haul. The return trip will be uphill and will result in the longer times. A speed limit of 40 km/hr was assumed on the loaded downhill.

4.4.5 Total Cycle Times

Cycle Time = Load + Haul + Dump + Return

Waste:

44 m^3 Shovels = 2.4 + 6.0 + 1.0 + 3.5 = 12.9 minutes/truck

26 m^3 Shovel = 3.6 + 6.0 + 1.0 + 3.5 = 14.1 minutes/truck

23 m^3 Shovel = 4.2 + 6.0 + 1.0 + 3.5 = 14.7 minutes/truck

11.5 m^3 Shovel = 7.8 + 6.0 + 1.0 + 3.5 = 17.3 minutes/truck

Coal:

The average coal haul is 6 km

[http://www.canadianminingjournal.com/issues/oct99/page11_fording_river_coal.asp; 2001].

30 m^3 FEL = 4.2 + 8.55 + 1.5 + 10.52 = 24.8 minutes/ truck

15 m^3 FEL = 8.45 + 8.55 + 1.5 + 10.52 = 29.0 minutes/ truck

The maximum number of trucks that can be accommodated by each type of shovel on an hourly basis can be estimated by dividing 60 by the total time to load each truck.

44 m^3 Shovels = 2.4 / 60 = 25 trucks / hour = 25 * 185 tonnes = 4,625 tph

26 m^3 Shovel = 3.6 / 60 = 16.7 trucks/hour = 16.7 * 185 tonnes = 3,089.5 tph

23 m^3 Shovel = 4.2 / 60 = 14.3 trucks/hour = 14.3 * 193 tonnes = 2759.9 tph

11.5 m^3 Shovel = 7.2 / 60 = 7.7 trucks/hour = 7.7 * 193 tonnes = 1486.1 tph

With all the shovels operating at capacity, the maximum production that can be realized is 113.7 trucks per hour. This is about 21,211 tonnes per hour, or 156 million tonnes per year based on the 7,371 operating hours per year.

In the model, the small shovel is not used – it is assumed that it is used as a spare. From the travel times above the following assignments were made:

6 trucks were assigned to each of the large shovels (18 trucks)

4 trucks were assigned to the 26 m^3 shovel

4 trucks were assigned to the 23 m^3 shovel

The times and numbers of equipment were checked with the use of the Cat Fleet Productivity and Costing program (version 3.0, 1997). For the purpose of the simulation, availability was set to 100%, no bunching was allowed to occur and operator efficiency was set to 100%.

From the preliminary simulation, the following results were obtained:

TOTAL Waste	144.952 (million tonnes)
Waste tph	19665.132

This production was achieved using a total of 26 trucks, leaving 6 trucks as spares (the Haulpak 930E is not utilized in the simulation since there is only one available). Some waste is moved at Fording River with a dragline; however no information was available on what this quantity is. The results for the waste were within 5% of the values calculated earlier based on reported numbers, and should be adequate for the model. When the coal haul was modeled it was found that there was an excess of capacity in both the loading and hauling capacity available. It was decided that, given the equipment list for the operation, it was most likely that coal hauling was only carried out during the day shift. The simulation was modified to reflect this, and reasonable production values were obtained.

Total Raw Coal	12.037 (million tonnes)
Coal tph	1635.290
Total Clean Coal	7.806 (million tonnes)

The resulting coal haul utilized the two large front-end loaders with 6 trucks assigned to each of them.

4.5 Model Concept

The operation was broken down into four parts: waste haulage, coal haulage, wash plant and the unit train. All loading operations took place at the same distance to dumps or stockpiles so that all travel times from load to dump were the same. No dynamic dispatching was utilized – the equipment was running in what is termed fully locked mode, with the trucks being tied to both load and dump locations.

Diagrammatically, the waste model is shown in Figure 7.

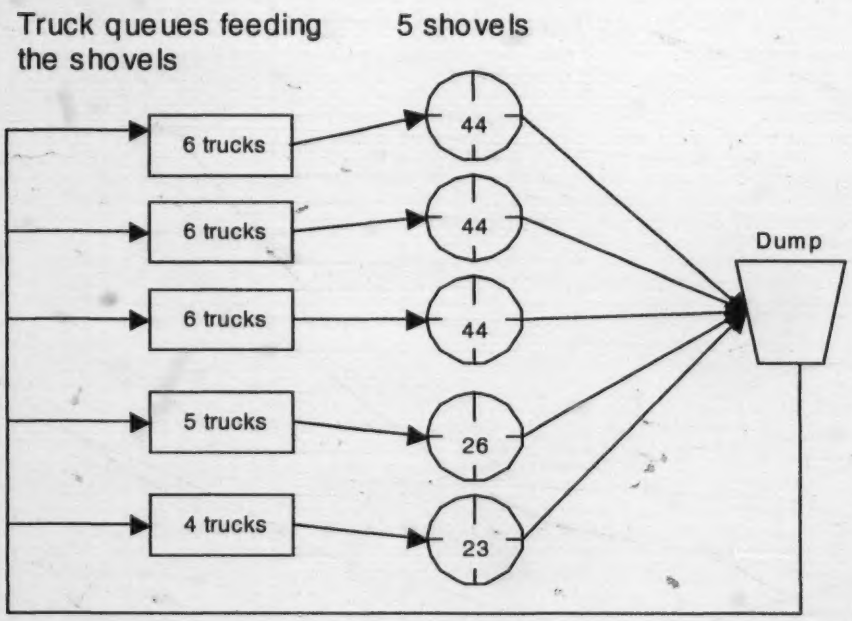

Figure 4-1: Schematic of the waste haulage.

The coal haulage model appears identical to the waste haulage except for the number of shovels and trucks and the dump is replaced by the stockpile.

The wash plant is assumed to be a continuous operation and would run as long as there was raw coal available, feeding into a clean coal stockpile.

The unit train operation is relatively simple since there is only one train moving between the mine and the terminal.

4.6 The AweSim Model

The coal mine operation again lends itself well to being modeled utilizing the network concept. The basic concept of the network model is that an entity moves along paths (activities) in a temporal relationship. The entities can be assigned attributes, which can affect the movement of the entity through the system, can trigger other activities or be changed. The entity attributes are similar to local variables in a traditional programming language. The objects that move through a mine are trucks, and therefore it was decided to model them as entities. The attributes, identified for the trucks, were: size (tonnage), shovel assignment, load time, full travel time, dump time and empty return time.

The shovels, considered stationary, could be modeled as a resource or as a queue. Either method would work, but since other models have been built utilizing queues to represent the shovels [Szymanski, JK, Srajer, V. and Kempke][Pritsker, AB] this was the method adopted. The queue node is a holding place for entities waiting to move onto an activity. The activity emanating from the queue is termed a service activity and has at least one server associated with it. In this case the activity being represented is the loading operation and the server is the shovel. The duration of the activity is the load time for the

truck on that shovel. The simulation software automatically collects statistics on the queues.

The coal haul was modeled identically to the waste haul as far as the trucks and shovels are concerned.

In operation, coal cannot be moved until it has been exposed. For the simulation, this connection was established by utilizing the stripping ratio on a tonne/tonne basis. In order to be able to move one tonne of coal, twelve tonnes of waste has to be moved. This connection between the coal haul and waste haul was made through a global variable, XX[5]. For every tonne of waste delivered to the dump, the amount of uncovered coal was increased by 1/12 of a tonne. In an actual operation, the coal loading cannot be too closely located in space to the waste operation or interference will take place between the equipment. In addition, there should also be an excess of coal exposed so that downed shovels will not immediately shutdown the coal operation.

Two additional node types were introduced in the coal simulation. A gate was used to model the shifts, since coal was only hauled half the time. Gates can have two states – open or closed. In the open state, entities flow through with no delay. If the gate is closed, the entities must wait in an await node (special queue node) for the gate to be opened. The operation of the shift gate was controlled by an independent network, which had a single entity moving through it opening and closing the gate after 10.5 hours. A second gate was utilized to control the coal operation if the 'exposed' coal fell below a specified level. This gate was controlled by two detect nodes. The detect node monitors the state of a variable and triggers the release of an entity when the condition is met. One detect node opened the gate and the second closed it. The threshold values assigned were that the coal

haul would not start until there was at least 45,000 tonnes of exposed coal.(about 2.5 shifts) and shut down at 4500 tonnes (less than 3 hours of hauling remaining).

The wash plant would most logically be modeled using continuous variables, since it is assumed to run 24 hours/day, seven days a week. For the purpose of the initial base model, the wash plant was modeled utilizing network techniques as well. This should not affect the outcomes of the simulation, unless the wash plant was to be looked at in detail. If more information was required with respect to the wash plant, this portion of the model should be rewritten.

An entity is generated at the start of the simulation and moves in a loop through a gate node. Reported output from the wash plant as mentioned earlier was 25,000 tonnes per day. This converts to 1041 tonnes of clean coal/hour. With a recovery of 66%, this would use 1802 tonnes of raw coal. When the entity leaves the gate node, the activity takes 1 hour of time and decreases the raw coal stockpile (global variable XX[6]) by 1802 tonnes and increases the clean coal pile by 1041 tonnes. The entity is then routed back to the gate. The gate is controlled by two detect nodes used to monitor the level of the raw coal pile. If the level drops below 10 hours of processing, the operation is stopped, and reopened when the level reaches 100 hours worth of raw coal.

Finally the unit train is modeled similar to the wash plant. In this case the activity duration is set to 82 hours, the return trip time for a unit train. The gate levels are set to close at 5,000 tonnes and re-open at 15,000 tonnes.

4.6.1 Running the Model

The initial model was created using the fixed times and quantities as outlined previously. The simulation was then run for a period of one year (7,371 hours) and the outputs

reviewed. There will be some delay for the system to achieve steady state (raw and clean coal inventories to build up) but this was accounted for in the system by initializing the raw coal and clean coal inventories. These initial amounts were set to less than 1% of the expected coal movements.

The simulation was run for a total of 7,371 hours, and statistics were collected.

4.7 Base Model Results

Total material quantities moved by the simulation annually are:

Total Waste	158.913 Million tonnes
Waste tph	16958.000
Total Raw Coal	13.206 million tonnes
Coal tph	1409.294
Total Clean Coal	8.480 million tonnes
Coal Train	7.175 million tonnes

From the queue statistics:

The average wait for the shovels was 0.025 hours, or 90 seconds. This would indicate that the shovels are producing at maximum capacity.

The gate statistics for the base run are shown in Table 4. As would be expected the shift gate, is open half the time representing the coal haul being carried out only during the day shift. There were times at which the wash plant and coal stocks fell below the threshold values assigned to them and were shut down.

Gate	Label	Current Status	Fraction of time open
1	SHIFT	OPEN	0.500
2	COAL_STOCK	OPEN	0.697
3	WASH_PLANT	OPEN	0.883

Table 4-1: Gate Statistics

In the following simulations, a triangular distribution was used to model the variability of the different activities. Since no data was available, the triangular distribution was utilized [Ellis, D. W. 2007]. In all cases the mode for the distribution was the value used in the base case and the minimum time set to 10% less and maximum time set to 25% greater, since it is felt that more factors would contribute to an increase in the times than to a decrease.

4.7.1 Scenario Number 1: Load Time Variability

The first scenario introduced variability into the loading times for the trucks. The results of the run were:

TOTAL Waste	138.025 million tonnes
Waste tph	18725.371
Total Raw Coal	11.461 million tonnes
Coal tph	1557.085
Total Clean Coal	7.418 million tonnes
Coal Train	6.402 million tonnes

Overall waste production is 87% of the base case scenario.

4.7.2 Scenario Number 2: Variable Return Travel Times

The loading times are returned to the base case level, and the return travel times modeled using a triangular distribution. From previous studies [Blackwell, GH] it has been shown

that the most variability occurs in the empty return times in most haul situations. The reason is that when loaded, the truck travel times are governed more by the truck mechanics, and when empty the travel times are related more to the skill of the operators.

TOTAL Waste	144.573 million tonnes
Waste tph	19613.773
Total Raw Coal	12.006 million tonnes
Coal tph	1631.022
Total Clean Coal	7.602 million tonnes
Coal Train	6.574 million tonnes

Overall waste is 90% of the base level.

4.7.3 Scenario Number 3: Variable Haul Travel Times

From the base case level the haul times were modeled with the triangular distribution with the limits being 12.5% faster and 25% slower.

TOTAL Waste	144.226 million tonnes
Waste tph	19566.750
Total Raw Coal	11.977 million tonnes
Coal tph	1627.089
Total Clean Coal	7.602 million tonnes
Coal Train	6.574 million tonnes

Overall again the waste level is reduced to 90%.

4.7.4 Scenario Number 4: Increasing Haul Distances

It has been reported that the average haul distance will be increasing from 2 kilometers to 6 kilometers over the next few years. This scenario was modeled to see what effect the

increased haul distances will have on the production of the mine. The first results are doubling the haul distance to 4 kilometers and the second increasing the haul distance to 6 kilometers. For the purposes of this exercise, the return and haul times were simply doubled and tripled (this appeared valid when checked with Caterpillar Fleet Productivity software, keeping the total rolling resistance constant over the main haul portion). Actual times should be recalculated based on the haul road profiles.

4-kilometer haul

TOTAL Waste	93.575 million tonnes
Waste tph	12695.080
Total Raw Coal	7.778 million tonnes
Coal tph	1057.421
Total Clean Coal	5.082 million tonnes
Coal Train	4.066 million tonnes

In looking at the gates controlling the operations linked to the haul, it is observed that the coal haul operation only has enough material to operate 44% of the time, and the plant 66%.

GATE LABEL	STATE	PER CENT
SHIFT	OPEN	0.500
COAL_STOCK	CLOSED	0.438
WASH_PLANT	OPEN	0.660

Table 4-1: Gate Statistics 4 Kilometre Haul

6-kilometer haul

TOTAL Waste	66.105 million tonnes
Waste tph	8968.346
Total Raw Coal	5.462 million tonnes
Coal tph	741.442
Total Clean Coal	3.591 million tonnes
Coal Train	2.587 million tonnes

The effect is even more dramatic with the coal haul operating only 33.5% of the time and the wash plant operating 43.5%.

GATE LABEL	STATE	PER CENT
SHIFT	OPEN	0.500
COAL_STOCK	OPEN	0.335
WASH_PLANT	CLOSED	0.465

Table 4-2: Gate Statistics 6 Kilometre Haul

The 4-kilometer haul would reduce productivity to 58% of the base level, and the 6-kilometer haul to 41%.

4.8 Conclusions

From the simulations carried out it can be seen the increased haulage distances are going to have a major impact on the operation of the mine. Tripling the haul distance will greatly reduce the productivity of the mine due to the shovels being idle waiting for

trucks. There will have to be an increase in the number of trucks being utilized at the mine. By increasing the number of trucks, the average production of the mine will increase, but there will be larger overall fluctuations in productivity. From this simple model, the importance of the haul distance can be readily observed and the careful planning of the mine with respect to the location of waste dumps and wash plants is extremely important.

When a triangular distribution was used to model the haul/return times, it would appear to have almost the same effect on this model. This may be due to the near perfect match factor of the operation. In the sample run (Appendix B), the shovel queues on average have less than one truck waiting.

4.9 Recommendations

From this work a basic model of the Fording River operation has been established. Balancing the model against actual operating values from the mine would be useful in establishing real-world time distributions for the various operations. Further work could be done on looking at equipment availabilities and production rates. Breakdowns could be added into the model and the effect on both long-term and short-term productivities examined.

Two ways this might be accomplished would be the use of gates to redirect truck entities from a downed shovel to a spare, or through the use of an event node to 'schedule' breakdowns based on the distributions.

Chapter Five: Discussion

In reviewing the two simulations carried out in this thesis, it has been shown how the use of simulation can aid in understanding and improving a mining operation.

In the underground hoist simulation it was demonstrated that by utilizing a very simple scheduling algorithm, a large gain in the efficient movement of loads within an underground mine could be achieved. Although this model only looked at a small portion of the total underground operation in isolation, increasing the efficiency of the operation of the hoist would have a large impact on the mine operation. It would be extremely expensive to increase the number of hoists so being able to deliver more loads with the same equipment would be a large improvement.

The underground hoist also highlighted the importance that animations can have in observing the running of a simulation. The animation allowed an error in the logic of the model to be quickly and easily detected and corrected. Although there was still an average of 11 loads waiting to be moved by the hoist, it was seeing during the animations that the there were times when the load queue was empty.

In the second simulation, an entire mine was modeled with the four major components being included – waste production, coal production, processing and transportation. One of the outcomes of this model highlighted the extreme importance of adequately planning for the location of waste dumps over the life of the mine. Increasing the haul distance from 2 kilometres to 4 kilometres and finally to the planned 6 kilometres greatly decreased the amount of coal which could be moved. Without proper planning, the entire operation could easily move from a profitable enterprise to an un-profitable one.

Although the model was not calibrated against actual operating data from a mine, the trends identified in the simulation should still be valid. If data were to be available for a specific mine, it would be relatively easy to adjust the equipment and operating parameters to match the new scenario.

Both models would benefit from multiple realizations being carried out to provide a distribution of values rather than the single average values reported in this work. In the AweSIM environment it is a simple operation to carry out multiple runs of a single scenario.

Chapter Six: Conclusion

The results of this thesis have shown that the use of a general purpose simulation language can be and still is an effective tool in the modeling of mining operations. With the complexity and diversity of mining operations, it may not be possible to use more specialized software to adequately capture the dynamics of the mining operation.

In the thesis, it was shown that basic changes to an operation can have major consequences on the operation of that system and any systems related to it. If these changes are not adequately understood, they could lead to the mine moving from a position of profitability to one of loss.

The two models represented two diverse scales of operation. The hoist model demonstrated a small scale simulation of a single operation isolated from its environment. The model showed that through a simple scheduling algorithm, large gains could be achieved in the efficiency of its operation. The second model, of the surface mine demonstrated that on the total mine scale a change in one operation, in this instance the waste haul, can have dramatic downstream implications on other related operations.

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APPENDIX A: HOISTING SIMULATION

A.1. Statement Model of the Cage Network

A.1.1. Control Statements:

```
GEN,"Doug Booth","Hoist Simulation",April 2000,1,YES,YES;
LIMITS,3,1,,9,1;
INTLC,{{xx[1],1}};
EQUIVENCE,{cl,xx[1]},{dur,atrib[1]},{row,atrib[3]},{col,atrib[4]},{lp,atrib[5]},
{ol,atrib[6]}, {dl,atrib[7]}, {rt,atrib[8]}};
ARRAY,2,21,{0,0.0034,0.0300,0.0439,0.0601,0.0601,0.0903,0.1113,0.1310,0.1368,
0.2204, 0.2435,0.3990,0.4686,0.5057,0.5150,0.9014,0.9095,0.9524,0.9988,1.0000};
ARRAY,3,21,{0,0.0048,0.0344,0.0526,0.0708,0.0724,0.0876,0.1041,0.1192,0.1225,
0.1899,0.2031,0.3427,0.4084,0.4512,0.4579,0.8783,0.9063,0.9538,0.9983,1.0000};
 ARRAY,4,21,{0,0.789,0.922,1.056,1.189,1.322,1.456,1.589,1.615,1.722,1.856,
1.989,2.122,2.389,2.656,2.789,2.922,3.189,3.242,3.296,3.409};
ARRAY,1,21,{0,400,600,800,1000,1200,1400,1600,1640,1800,2000,2200,2400,
2800,3200,3400,3600,4000,4080,4160,4330};
```

```
INITIALIZE,0.0,10080,YES,,NO;
NET;
FIN;
```

A.1.2. Network Statements:

```
RESOURCE,1,cage,1,{1,2};
level prob (lp = atrib[5])
current level (cl = xx[1])
old level (ol = atrib[6])
duration (dur = atrib[1])
down level (dl = atrib[7])
index (row = atrib[3])
index (col = atrib[4])
request time (rt = atrib[8])
Down: CREATE,expon(15),expon(15),rt,,1;
ACTIVITY;
ASSIGN,{{ROW,2},{etype,1},{ltrib[1],2}},1;
ACTIVITY;
Begin: ASSIGN,{{col,2},{lp,DRAND}},1;
ACTIVITY;
```

```
C_Level: GOON,1;
ACTIVITY,,,lp <= array[row,col];
ACTIVITY,,,,"F_Level";
GOON,1;
ACTIVITY,15,,etype == 1,"down_1",,"Down_req";
ACTIVITY,16,,etype == 2,"up_1",,"Up_req";
F_Level: ASSIGN,{{col,col + 1}},1;
ACTIVITY,,,,"C_Level";
UP: CREATE,expon(10),expon(10),rt,,1;
ACTIVITY;
ASSIGN,{{ROW,3},{etype,2},{ltrib[1],1}},1;
ACTIVITY,,,,"Begin";
down_1: ASSIGN,{{ol,1},{dl,col}},1;
ACTIVITY;
combine: GOON,1;
ACTIVITY,17,,,,,"total req";
ASSIGN,{{dur,abs(array[4,cl] - array[4,ol]) + abs(array[4,ol] - array[4,dl])}},1;
ACTIVITY;
wait: AWAIT,2,{{cage,1}},ALLOC(1),,NONE,1;
ACTIVITY;
ASSIGN,{{ll[1],etype}},1;
ACTIVITY;
```

```
FINDAR,2,(ltrib[1]==LL[1])&&(MAX(atrib[6],atrib[7])<xx[1]),1,FORWARD,1
,"remove" ,{{dur,xx[2]}, {ltrib[1],3}},xx[3],1;
ACTIVITY,1,dur,,,1,"moving";
FREE,{{cage,1}},1;
ACTIVITY;
ASSIGN,{{xx[1],dl}},1;
ACTIVITY;
move: COLCT,,dur,"move time",,,,1;
ACTIVITY;
stats: COLCT,,tnow - rt,"time in system",,,,1;
ACTIVITY;
COLCT,,col,"array column",19,2,1,1;
ACTIVITY;
TERMINATE;
up_1: ASSIGN,{{ol,col},{dl,1}},1;
ACTIVITY,,,,"combine";
;Loads picked up from queue
remove: COLCT,,xx[3],"moved",,,,1;
ACTIVITY,20,dur,,"stats";
;Daily Interruptions
CREATE,,210,,1,1;
 ACTIVITY;
 rope_1: PREEMPT,1,,1,,,1;
```

```
ACTIVITY,2,60,,,,"rope_1";
FREE,{{1,1}},1;
ACTIVITY,,1110;
rope_2: PREEMPT,1,,1,,,1;
ACTIVITY,3,60,,,,"rope_2";
FREE,{{1,1}},1;
ACTIVITY,,210,,"rope_1";
CREATE,,840,,1,1;
ACTIVITY;
mechanical: PREEMPT,1,,1,,,1;
ACTIVITY,4,14,,,,"mechanical";
FREE,{{1,1}},1;
ACTIVITY,,1426,,"mechanical";
;Weekly Interruptions
CREATE,,270,,1,1;
ACTIVITY;
cage: PREEMPT,1,,1,,,1;
ACTIVITY,5,120,,,,"insp_cage";
FREE,{{1,1}},1;
ACTIVITY,,9960,,"cage";
CREATE,,90,,1,1;
ACTIVITY;
counter_wt: PREEMPT,1,,1,,,1;
```

```
ACTIVITY,6,60,,,,"insp_cwt";
FREE,{{1,1}},1;
ACTIVITY,,10020,,"counter_wt";
CREATE,,780,,1,1;
ACTIVITY;
electrical: PREEMPT,1,,1,,,1;
ACTIVITY,7,60,,,,"insp_elec";
FREE,{{1,1}},1;
ACTIVITY,,10020,,"electrical";
;Man Hoisting
CREATE,,390,,1,1;
ACTIVITY;
man_s1: PREEMPT,1,,1,,,1;
ACTIVITY,8,120,,,,"men_1";
FREE,{{1,1}},1;
ACTIVITY,,195;
;man_s2: PREEMPT,1,,1,,,1;
ACTIVITY,9,30,,,,"men_2";
FREE,{{1,1}},1;
ACTIVITY,,135;
man_s3: PREEMPT,1,,1,,,1;
ACTIVITY,10,120,,,,"men_3";
FREE,{{1,1}},1;
```

```
ACTIVITY,,360;
man_s4: PREEMPT,1,,1,,,1;
ACTIVITY,11,60,,,,"men_4";
FREE,{{1,1}},1;
ACTIVITY,,420,,"man_s1";
;Surface Mine Blast Delays
CREATE,,660,,1,1;
ACTIVITY;
blast_1: PREEMPT,1,,1,,,1;
ACTIVITY,12,60,,,,"blast_1";
FREE,{{1,1}},1;
ACTIVITY,,2820;
blast_2: PREEMPT,1,,1,,,1;
ACTIVITY,13,60,,,,"blast_2";
FREE,{{1,1}},1;
ACTIVITY,,4260;
blast_3: PREEMPT,1,,1,,,1;
ACTIVITY,14,60,,,,"blast_3";
FREE,{{1,1}},1;
ACTIVITY,,2820,,"blast_1";
;Animation for Day & Night bitmap
CREATE,INF,0.0,,1,1;
ACTIVITY,18,360;
```

```
day: GOON,1;
ACTIVITY,,720;
night: GOON,1;
ACTIVITY,19,720,,"day";
```

A.2. Awesim® Output

Output from the Cage Model – No Scheduling

Table A1. Observed statistics report for scenario SKIP

Label	Mean Value	Standard Deviation	Number of Observations	Minimum Value	Maximum Value
move time	3.971	1.468	1617	0.789	6.592
time in system	725.844	241.493	1617	1.989	1088.83
array column	14.408	4.168	1617	2	21

Table A2. File Statistics report for scenario SKIP

File Number	Label or Input Location	Average Length	Standard Deviation	Maximum Length	Current Length	Average Wait Time
1	RES. CAGE	0.006	0.077	1	0	4.615
2	RES. CAGE	122.096	43.582	186	147	697.298
0	Event Calendar	11.631	0.495	12	11	32.85

Table A3. Activity statistics report for scenario SKIP

Activity Number	Label or Input Location	Average Utilization	Standard Deviation	Entity Count	Maximum Utilization
1	moving	0.637	0.481	1617	1
2	rope_1	0.042	0.2	7	1
3	rope_2	0.037	0.189	6	1
4	mechanical	0.01	0.098	7	1
5	insp_cage	0.012	0.108	1	1
6	insp_cwt	0.006	0.077	1	1
7	insp_elec	0.006	0.077	1	1
8	men_1	0.083	0.276	7	1
9	men_2	0.021	0.143	7	1
10	men_3	0.083	0.276	7	1
11	men_4	0.042	0.2	7	1
12	blast_1	0.006	0.077	1	1
13	blast_2	0.006	0.077	1	1
14	blast_3	0.006	0.077	1	1
15	Down_req	0	0	695	1
16	Up_req	0	0	1070	1
17	total req	0	0	1765	1
18	Line 121	0.036	0.186	1	1
19	Line 125	0.464	0.499	6	1

Table A4. Resource statistics report for scenario SKIP

Resource Number	Resource Label	Average Util	Standard Deviation	Current Util.	Maximum Util.
1	CAGE	0.996	0.059	1	1

Resource Number	Current Capacity	Average Available	Current Available	Minimum Available	Maximum Available
1	1	0.004	0	0	1

A.3. Output from the Cage Model – Scheduling

Table A5. Observed statistics report for scenario SKIP

Label	Mean Value	Standard Deviation	Number of Observations	Minimum Value	Maximum Value
Move time	4.213	1.501	1456	0.922	6.592
Time in system	104.922	107.825	1764	0.08	510.564
Array column	14.438	4.162	1764	2	21
Moved	1	0	308	1	1

Table A6. File Statistics report for scenario SKIP

File Number	Label or Input Location	Average Length	Standard Deviation	Maximum Length	Current Length	Average Wait Time
1	RES. CAGE	0.021	0.144	1	0	4.349
2	RES. CAGE	17.754	19.013	87	1	101.393
0	Event Calendar	11.587	0.515	13	11	23.134

Table A7. Activity statistics report for scenario SKIP

Activity Number	Label or Input Location	Average Utilization	Standard Deviation	Entity Count	Maximum Utilization
1	moving	0.609	0.488	1456	1
2	rope_1	0.042	0.200	7	1
3	rope_2	0.036	0.186	6	1
4	mechanical	0.010	0.098	7	1
5	insp_cage	0.012	0.108	1	1
6	insp_cwt	0.006	0.077	1	1
7	insp_elec	0.006	0.077	1	1
8	men_1	0.083	0.276	7	1
9	men_2	0.021	0.143	7	1
10	men_3	0.083	0.276	7	1
11	men_4	0.037	0.188	6	1
12	blast_1	0.006	0.077	1	1
13	blast_2	0.006	0.077	1	1
14	blast_3	0.006	0.077	1	1
15	Down_req	0.000	0.000	695	1
16	Up_req	0.000	0.000	1070	1
17	total req	0.000	0.000	1765	1
18	Line 128	0.036	0.186	1	1
19	Line 132	0.464	0.499	6	1
20	Line 55	0.000	0.000	308	1

Table A8: Resource statistics report for scenario SKIP

Resource Number	Resource Label	Average Util.	Standard Deviation	Current Util.	Maximum Util.
1	CAGE	0.962	0.192	1	1

Resource Number	Current Capacity	Average Available	Current Available	Minimum Available	Maximum Available
1	1	0.038	0	0	1

APPENDIX B: COAL MINE SIMULATION

B.1. AweSim Control Statements

```
1 GEN,"Doug Booth","Thesis - Triangular Load increase",12/09/00,1,YES,YES;
2 LIMITS,8,-1,-1,6,-1,-1;
3 INITIALIZE,0.0,9371,YES,,NO;
4 EQUIVALENCE,{{SHOVEL,ATRIB[2]},{LOAD,ATRIB[3]},
{TRAVEL_FULL,ATRIB[4]},{DUMP,ATRIB[5]}, {TRAVEL_EMPTY,ATRIB[6]}};
5 TIMST,1,XX[1]/1000000,"TOTAL Waste",0,0.0,1.0;
6 TIMST,2,XX[2],"Waste tph",0,0.0,1.0;
7 TIMST,3,XX[3]/1000000,"Total Raw Coal",0,0.0,1.0;
8 TIMST,4,XX[4],"Coal tph",0,0.0,1.0;
9 TIMST,5,XX[7]/1000000,"Total Clean Coal",0,0.0,1.0;
10 TIMST,6,XX[8]/1000000,"Coal Train",0,0.0,1.0;
11 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
12 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
13 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
14 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
15 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
16 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
17 ENTRY,1,SHOVELS,{0,185,1,0.04,0.15,0.017,0.058};
18 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};
19 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};
20 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};
```

21 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};

22 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};

23 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};

24 ENTRY,2,SHOVELS,{0,185,2,0.04,0.15,0.017,0.058};

25 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

26 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

27 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

28 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

29 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

30 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

31 ENTRY,3,SHOVELS,{0,185,3,0.04,0.15,0.017,0.058};

32 ENTRY,4,SHOVELS,{0,185,4,0.06,0.15,0.017,0.058};

33 ENTRY,4,SHOVELS,{0,185,4,0.06,0.15,0.017,0.058};

34 ENTRY,4,SHOVELS,{0,185,4,0.06,0.15,0.017,0.058};

35 ENTRY,4,SHOVELS,{0,185,4,0.06,0.15,0.017,0.058};

36 ENTRY,4,SHOVELS,{0,185,4,0.06,0.15,0.017,0.058};

37 ENTRY,6,LOADERS,{0,154,6,0.07,0.2,0.017,0.2};

38 ENTRY,6,LOADERS,{0,154,6,0.07,0.2,0.017,0.2};

39 ENTRY,6,LOADERS,{0,154,6,0.07,0.2,0.017,0.2};

40 ENTRY,6,LOADERS,{0,154,6,0.07,0.2,0.017,0.2};

41 ENTRY,6,LOADERS,{0,154,6,0.07,0.2,0.017,0.2};

42 ENTRY,7,LOADERS,{0,154,7,0.07,0.2,0.017,0.2};

43 ENTRY,7,LOADERS,{0,154,7,0.07,0.2,0.017,0.2};

```
44 ENTRY,7,LOADERS,{0,154,7,0.07,0.2,0.017,0.2};
45 ENTRY,7,LOADERS,{0,154,7,0.07,0.2,0.017,0.2};
46 ENTRY,7,LOADERS,{0,154,7,0.07,0.2,0.017,0.2};
47 MONTR,CLEAR,2000;
48 RECORD,1,RETURN.xls,TNOW,"TIME",{AWESIM,EXCEL},
"%8.1f",2000,TTFIN,147,{{xx[1]/1000000,"TWaste","%6.1f"},{XX[2],"W_tph","%8.0f
"},{XX[3]/1000000,"T_RCoal","%6.1f"},{XX[4],"RCoal_tph","%8.0f"},{XX[7]/10000
00,"T_CCoal","%6.1f"}};
49 NET;
50 FIN;
```

B.2. Network Statements

```
1 GATE,1,Shift,CLOSED,{11};
2 GATE,2,Coal_Stock,CLOSED,{12};
3 GATE,3,wash_plant,CLOSED,{13};
4 GATE,4,Unit_Train,CLOSED,{14};
5 ;WASTE HAUL
6 ;COAL HAUL
7 ;Coal is only hauled on day shift
8 CREATE,INF,0.0,,1,1;
9 ACTIVITY;
10 Day_shift: OPEN,1,1;
11 ACTIVITY,,10.5;
12 CLOSE,1,1;
13 ACTIVITY,,10.5,,"Day_shift";
14 ;Maintain a 12:1 tonne/tonne stripping ratio
15 Coal_stock: DETECT,XX[5],POSITIVE,45000,INF,1;
16 ACTIVITY;
17 OPEN,2,1;
18 ACTIVITY;
19 TERMINATE,INF;
20 Waste_low: DETECT,XX[5],NEGATIVE,4500,INF,1;
21 ACTIVITY;
```

```
22 CLOSE,2,1;
23 ACTIVITY;
24 TERMINATE,INF;
25 ;Coal Wash Plant
26 CREATE,1,0.0,,1,1;
27 ACTIVITY;
28 Plant: AWAIT,13,{{3,1}},ALL,,NONE,1;
29 ACTIVITY,,1;
30 ASSIGN,{{XX[6],XX[6] - 1832},{XX[7],XX[7] + 1191},{XX[8],XX[8] +
1191}},1;
31 ACTIVITY,,,,"Plant";
32 DETECT,XX[6],POSITIVE,183200,INF,1;
33 ACTIVITY;
34 OPEN,3,1;
35 ACTIVITY;
36 TERMINATE,INF;
37 DETECT,XX[6],NEGATIVE,18320,INF,1;
38 ACTIVITY;
39 CLOSE,3,1;
40 ACTIVITY;
41 TERMINATE,INF;
42 ;Train
43 CREATE,INF,0.0,,1,1;
```

```
44 ACTIVITY;
45 Load_rdy: AWAIT,14,{{4,1}},ALL,,NONE,1;
46 ACTIVITY;
47 ASSIGN,{{XX[8],XX[8] - 11550}},1;
48 ACTIVITY,,82,,"Load_rdy",,"Train_haul";
49 DETECT,XX[8],POSITIVE,15000,INF,1;
50 ACTIVITY;
51 OPEN,4,1;
52 ACTIVITY;
53 TERMINATE,INF;
54 DETECT,XX[8],NEGATIVE,5000,INF,1;
55 ACTIVITY;
56 CLOSE,4,1;
57 ACTIVITY;
58 TERMINATE,INF;
59 SHOVELS: QUEUE,ASSERT(SHOVEL,1,4),0,INF,NONE;
60 ACTIVITY,ASSERT(SHOVEL,1,4),LOAD,,"ENDL",1;
61 ENDL: GOON,1;
62 ACTIVITY,5,TRAVEL_FULL,,"DUMP",,"TRAVEL_FULL";
63 DUMP: QUEUE,5,0,INF,NONE;
64 ACTIVITY,10,DUMP,,,3,"FROM_DMP";
65 ASSIGN,{{XX[1],XX[1] + ATRIB[1]},{XX[2],XX[1]/TNOW},{XX[5],XX[5] +
(ATRIB[1]/12)}},1;
```

```
66 ACTIVITY,11,TRAVEL_EMPTY,,"SHOVELS",,"TRAVEL_EMPTY";
67 COAL_DNE: GOON,1;
68 ACTIVITY,12,TRAVEL_FULL,,"Stockpile",,"TRAVEL_FULL";
69 Stockpile: QUEUE,10,0,INF,NONE;
70 ACTIVITY,13,DUMP,,,3,"FROM_DMP";
71 ASSIGN,{{XX[3],XX[3] + ATRIB[1]},{XX[4],XX[3]/TNOW},{XX[6],XX[6]
ATRIB[1]},{XX[5],XX[5] - ATRIB[1]}},1;
72 ACTIVITY,14,TRAVEL_EMPTY,,,,"TRAVEL_EMPTY";
73 Day_shft: AWAIT,11,{{1,1}},ALL,,NONE,1;
74 ACTIVITY;
75 Coal_avail: AWAIT,12,{{2,1}},ALL,,NONE,1;
76 ACTIVITY,,,,"LOADERS";
77 LOADERS: QUEUE,ASSERT(SHOVEL,6,9),0,INF,NONE;
78 ACTIVITY,ASSERT(SHOVEL,6,9),LOAD,,"COAL_DNE",1;
```

B.3. AweSim Network Diagram

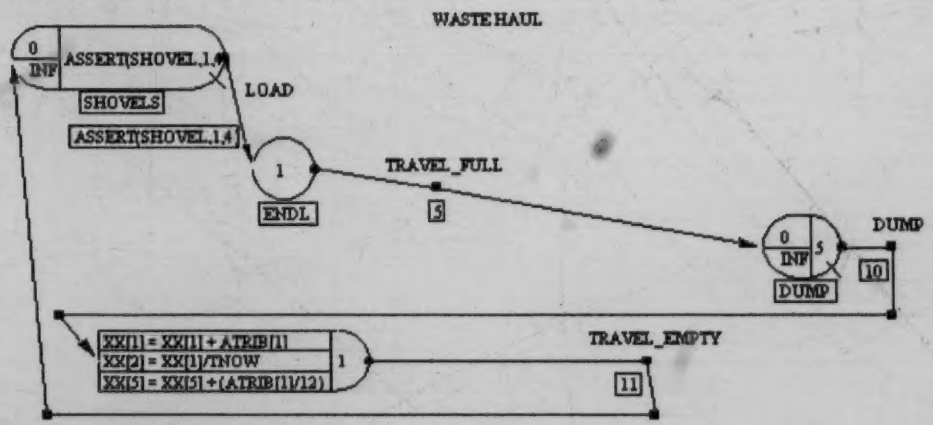

Figure B-1: Waste Haul

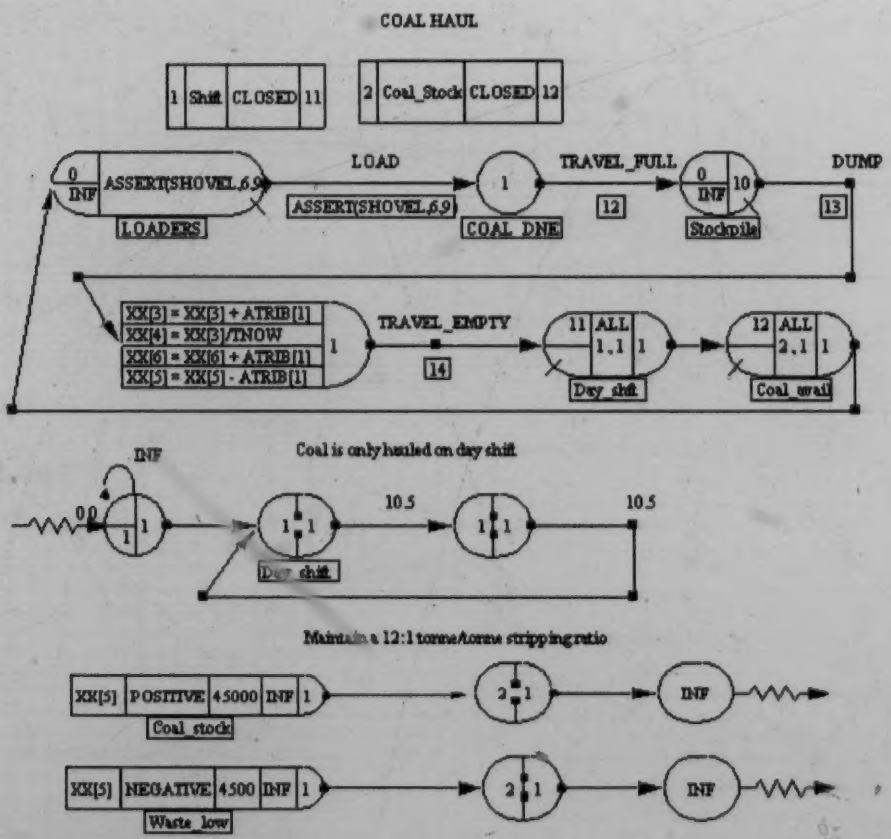

Figure B-1: Waste Haul

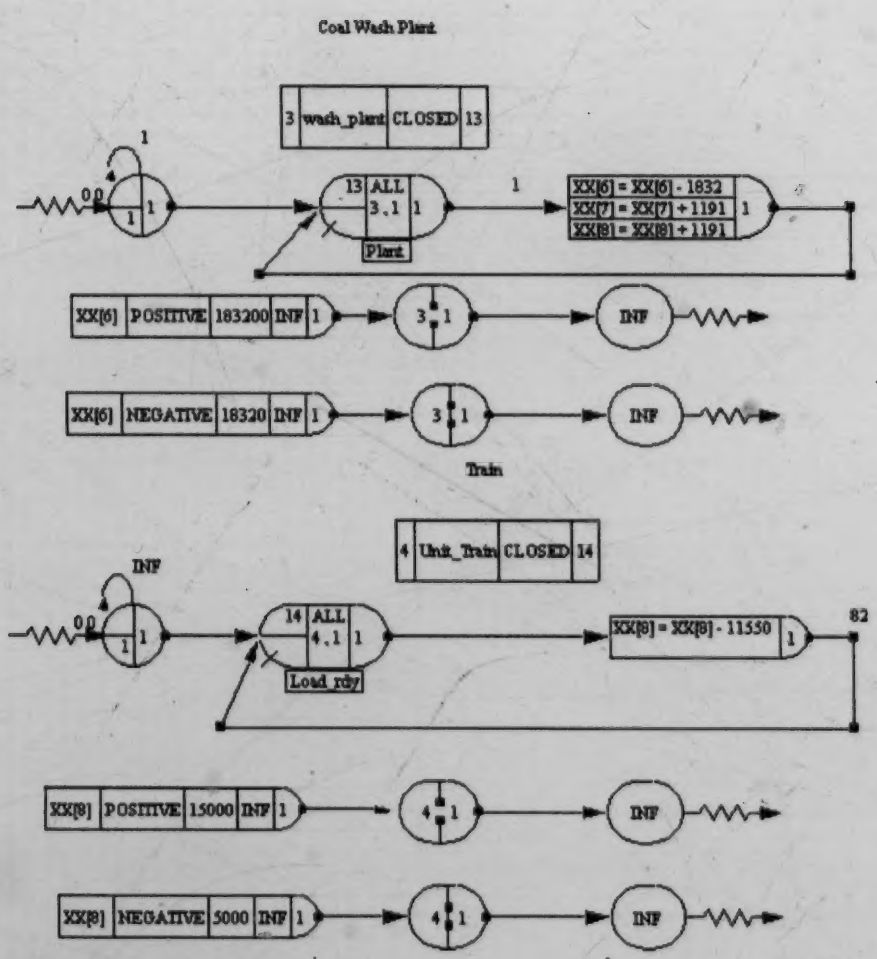

Figure B-3: Coal Wash Plant

B.4. Sample Summary Report

** AweSim SUMMARY REPORT **

Wed Dec 13 08:47:43 2000

Simulation Project : 632 Final Project - Triangular Load increase

Modeler : Doug Booth

Date : 12/09/00

Scenario : FR1_BASE

Run number 1 of 1

Current simulation time : 7371.000000

Statistics cleared at time : 0.000000

Table B-1: Statistics Report from the Base Scenario

Label Value	Mean Deviation	Standard Value	Minimum Value	Maximum Interval	Time
TOTAL Waste	72.474	41.845	0.000	144.952	7371.000
Waste tph	19661.176	120.392	0.000	19665.140	7371.000
Total Raw Coal	6.010	3.487	0.000	12.037	7371.000
Coal tph	627.180	118.639	0.000	3132.203	7371.000
Total Clean Coal	3.766	2.215	0.000	7.602	7371.000
Coal Train	3.263	1.915	0.004	6.584	7371.000

Table B-2: Base Scenario – Current Values at End of Simulation

Label	Current Value
TOTAL Waste	144.952
Waste tph	19665.132
Total Raw Coal	12.037
Coal tph	1635.290
Total Clean Coal	7.602
Coal Train	6.574

Table B-3: File Statistics Report from the Base Scenario

File Number	Input	Label or Location	Average Length	Standard Deviation	Maximum Length	Current Length	Average Wait Time
1	QUEUE	SHOVELS	0.625	0.484	5	0	0.025
2	QUEUE	SHOVELS	0.614	0.487	5	0	0.025
3	QUEUE	SHOVELS	0.523	0.5	5	0	0.021
4	QUEUE	SHOVELS	0.042	0.2	3	0	0.003
5	QUEUE	SHOVELS	0.427	0.495	3	0	0.03
6	QUEUE	LOADERS	0.075	0.45	5	5	0.014
7	QUEUE	LOADERS	0.075	0.45	5	5	0.014
10	QUEUE	Stockpi	0	0	1	0	0
11	GAT.	SHIFT	3.844	5.568	12	0	0.363
12	GAT.	COAL_STOCK	3.605	5.491	12	0	0.34
13	GAT.	WASH_PLANT	0.009	0.095	1	0	0.009
14	GAT.	UNIT_TRAIN	0.01	0.098	1	0	0.796
15	QUEUE	DUMP	0.227	0.487	2	0	0.002
0	Event	Calendar	32.923	5.903	44	32	0.07

Table B-4: Activity Statistics Report Base Scenario

Activity Number	Label or Input Location	Average Utilization	Standard Deviation	Entity Count	Maximum Utilization
5	Multiple definin	11.595	1.649	886262	14
11	TRAVEL_EMPTY	6.145	1.206	780953	8
12	TRAVEL_FULL	1.538	2.018	78162	6
14	TRAVEL_EMPTY	1.856	2.478	78162	6

Table B-5: Activity Current Utilization Base Scenario

Activity Number	Current Utilization
5	13
11	8
12	0
14	0

Table B-6: Service Activity Report for Base Scenario

Activity Number	Label or Input Location	Server Capacity	Entity Count	Average Utilization	Standard Deviation
1	Loading	1	184275	1	0
2	Loading	1	184275	1	0
3	Loading	1	184275	1	0
4	Loading	1	122849	1	0.001
5	Loading	1	886262	1	0
6	C_loading	1	39081	0.371	0.483
7	C_loading	1	39081	0.371	0.483
10	FROM_DMP	3	780961	1.801	1.167
13	FROM_DMP	3	78162	0.265	0.678

Table B-7: Server Utilization Report for Base Scenario

Activity Number	Current Utilization	Average Blockage	Maximum Idle Time or Servers	Maximum Busy Time or Servers
1	1	0	0	7371
2	1	0	0	7371
3	1	0	0	7371
4	1	0	0.012	3274.968
5	1	0	0	7371
6	1	0	28.297	10.57
7	1	0	28.297	10.57
10	1	0	3	3
13	0	0	3	2

Table B-8: Gate Statistics Report for Base Scenario

Gate Number	Gate Label	Current Status	Percent of Time Open
1	SHIFT	OPEN	0.5
2	COAL_STOCK	OPEN	0.697
3	WASH_PLANT	OPEN	0.991
4	UNIT_TRAIN	OPEN	0.989